Summary of Research Activities Report

For the research entitled

Russian-U.S. Partnership to Study the 23-km-diameter El'gygytgyn Impact Crater, Northeast Russia

Grant number:

NAG5-8722

For the period:

08/15/99 to 08/14/02

Submitted by: **Dr. Virgil L. Sharpton**
U.S. Principal Investigator

University of Alaska
Geophysical Institute
903 Koyukuk Drive
Fairbanks, AK 99775-7320

Buck.Sharpton@gi.alaska.edu
907-474-6663 (voice)
907-474-7290 (fax)

PARTICIPANTS:

Dr. Virgil L. Sharpton, (U.S. Principal Investigator)
Geophysical Institute, Fairbanks, AK

Dr. Pavel S. Minyuk (Russian Principal Investigator)
North East Interdisciplinary Scientific Research Institute, Magadan, Russia

Dr. Julie Brigham-Grette (Co-Investigator)
University of Massachusetts, Amherst, MA

Dr. Olga Glushkova (Co-Investigator)
North East Interdisciplinary Scientific Research Institute, Magadan, Russia

Dr. Paul Layer (Co-Investigator)
Geophysical Institute, Fairbanks, AK

Dr. Mikhail Raikevich (Co-Investigator)
North East Interdisciplinary Scientific Research Institute, Magadan, Russia

Dr. David Stone (Co-Investigator)
Geophysical Institute, Fairbanks, AK

Dr. Valdimir Smirnov (Co-Investigator)
North East Interdisciplinary Scientific Research Institute, Magadan, Russia

BACKGROUND: El'gygytgyn crater, located within Eastern Siberia, is a Pliocene-aged (3.6 Ma), well-preserved impact crater with a rim diameter of roughly 23 km. The target rocks are a coherent assemblage of crystalline rocks ranging from andesite to basalt. At the time of impact the region was forested and the Arctic Ocean was nearly ice-free. A 15-km lake fills the center of the feature and water depths are approximately 175 m. Evidence of shock metamorphism, -- including coesite, fused mineral glasses, and planar deformation features in quartz -- has been reported. This feature is one of the youngest and best preserved complex craters on Earth. Because of its remote Arctic setting, however, El'gygytgyn crater remains poorly investigated.

OBJECTIVES: The objectives of this three-year project are to establish and maintain a research partnership between scientists from Russia and the United States interested in the El'gygytgyn crater. The principal institutions in the U.S. will be the Geophysical Institute, University of Alaska Fairbanks and the University of Massachusetts Amherst. The principal institution in Russia will be the North East Interdiscuplinary Scientific Research Institute (NEISRI), which is the Far-East Branch of the Russian Academy of Science. Three science tasks are identified for the exchange program: (1) Evaluate impactite samples collected during previous field excursions for evidence of and level of shock deformation. (2) Build a high-resolution digital elevation model for the crater and its surroundings using interferometric synthetic aperture radar techniques on JERS-1, ERS-1, ERS-2, and/or RadarSat range-doppler data. (3) Gather all existing surface data available from Russian and U.S. institutions (DEM, remote sensing image data, field-based lithological and sample maps, and existing geophysical data) and assemble into a Geographic Information Systems database.

RESULTS:

1. ***Exchange visits***. The project helped support a total of 4 exchange visits:
   1.1. Each year Russian participants visited the U.S. institutes for 3-4 weeks to provide the U.S. participants with samples of impactites and other data from their studies of El'gygytgyn crater, to attend workshops and conferences in the U.S., and to develop plans for field excursions to the crater. During the third year this visit included participation in a workshop sponsored by the International Continental Drilling Program (ICDP) organized to develop a plan for extracting drill core samples form the sediments filling the crater lake as well as the underlying crater materials.
   1.2. One field visit to the crater was conducted during the summer of 2001 to collect additional samples and seismic data in preparation for submitting a proposal to the ICDP to drill the crater. Drs. Brigham-Grette and Nolan (UAF) attended from the U.S. side.

2. ***Computer Equipment for Russian Scientists***. Two research workstations were purchased by Russian participants using funds from this project. This equipment has been described and justified in the annual progress reports. Drs. Minyuk, Glushkova, Raikevich and Smirnov uses these computers to process data from the crater and to help with visualization and analysis.

3. ***SAR Imagery***. Approximately 450 synthetic aperture radar images of the crater have been processed, organized and analyzed. One of the more impressive results of this time-series study was the detection of a dark halo observed over the ice-covered crater lake in numerous winter scenes. Our analysis suggested that this halo indicates the position of the submarine central peak, characteristic of complex impact craters of this size. Seismic data collected in 2001 confirmed this idea and we have subsequently published an extensive paper on this study (Nolan et al., 2002; see Appendix I). This paper contains an explicit acknowledgement of the NASA JURRISS support.

4. ***Digital Elevation Model***. Using four tandem mission ERS-1/2 image pairs, we constructed a high-resolution digital elevation model of the El'gygytgyn crater region (~125 km x 125 km) and compared it to existing 1:50 000-scale topographic maps. These products will be valuable for planned field studies, for orthorectifying the IKONOS imagery, train correcting Landsat and SAR imagery, and assessments of how the crater has been eroded through time. A paper will be submitted to a peer-reviewed journal on the development of this DEM and its uses.

5. ***IKONOS Data Acquisition***. The project permitted us to acquire new high-resolution satellite data over the crater. In 2001 and 2002, 12 Ikonos scenes were acquired over the crater through the NASA Scientific Data Purchase program. These images were used to generate a controlled mosaic that we can use for a map base. In addition, they will be invaluable for the following research areas associated with ongoing binational exploration of the El'gygytgyn crater including hydrological studies, deformation studies, surface mapping, and change detection.

6. ***Landsat Data Acquisition.*** We purchased six Landsat 7 scenes over the crater using funds from this project. These images were used to further understand how the complex volcanic assemblage controlled asymmetries in the crater morphology.

7. ***Shock Metamorphism and Target Characterization.*** Thin sections of a total of 60 rock samples were made and analyzed using funds from this project. The information from this study was presented at the European Science Foundation Impact 7 meeting in Svalbard in 2001 by the Principal Investigator and a paper is being prepared for submittal to *Meteoritics and Planetary Science.*

8. ***Graduate Student Support.*** The JURRISS program provided partial but much-needed support for a graduate student, Ms. Cynthia Peters, to use the Landsat data, in conjunction with sample data and maps made available through this project to identify composition variations within the volcanic assemblage utilizing a supervised classification approach. Ms. Peters has presented two posters on this work at national meetings and is in the final year of her master's thesis work.

9. ***Undergraduate Student Support.*** The project supported an undergraduate assistant, Ms. Rosanna Campi, to translate 22 hard-to-find Russian publications on El'gygytgyn into English. A listing of these documents is provided in Appendix II. Ms. Campi is also responsible for developing and maintaining our website where these translations will be made available to all interested parties: http://www.gisp.gi.alaska.edu/.

10. ***Selection of the El'gygytgyn Crater for a Future ICDP Lake Drilling Campaign.*** Preliminary investigations of the crater and the international coalition developed in part by support from this program has led recently to the selection of El'gygytgyn as a high-priority site for upcoming deep drilling of the lake sediments. A workshop organized by Drs. Brigham-Grette and Minyuk to develop a long-term exploration strategy was held in Amherst, MA, November 10-12, 2001 (see Appendix III). A drilling proposal is now being prepared. The JURRISS program played a key role in bring personnel together to promote and implement this project.

11. ***Publications and Presentations.***

Brigham-Grette, Julie, Celeste Cosby, Mike Apfelbaum, and Matt Nolan, 2001. The Lake El'gygytgyn Sediment Core - a 300ka Climate Record of the Terrestrial Arctic. EOS Transactions, AGU, v. 82, n. 47, pg. F752.

Brigham-Grette, Julie, 2001, Modern Process Studies and Sedimentation, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Brigham-Grette, Julie, Olga Glushkova, Pavel Minyuk, Frank Neissen, Bernd Wagner, Matt Nolan, Conrad Kopsch, Celeste Cosby, A Smirnov, Mike Apfelbaum, and Grisha Federov, 2000. THE-IMPACT Project 2000: Terrestrial History of El'gygytgyn Crater lake - an International Multidisciplinary PaleoClimaTe Project. EOS Transactions, AGU, v. 81, n.48, pg. F206.

Brigham-Grette, Julie, 2001, Long Road to El'gygytgyn: Background, funding, and 1998/2000 field campaigns, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Glushkova, Olga, T. Stetsenko, V. Smirnov, and P. Minyuk, 2001, Modern Process Studies at Lake El'gygytgyn Stratigraphy and paleogeography of the Late Pleistocene and Holocene in region surrounding El'gygytgyn Lake, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Glushkova Olga and P. Minyuk, 2001, Geomorphology and Neogene Stratigraphy ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Layer, Paul, 2001, Volcanostratigraphy of the El'gygytgyn Basin and the Age of the Impact Event, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Minyuk, Pavel, V.Ya Borkhodoev, O. Yu. Glushkova, 2001, Inorganic Geochemistry Data of El'gygytgyn Sediments as a Proxy of Paleoclimate, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Melles, Martin, J. Brigham-Grette and P. Minyuk, 2001, Introduction to Needs and Current Planning for Supplementary Work, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Niessen, F., C. Kopsch, B. Wagner, M. Nolan, and J. Brigham-Grette, 2000. THE IMPACT Project: Seismic Investigation of Lake El'gygytgyn, NE Russia - Implications for Sediment Thickness and Depositional Environment. EOS Transactions, AGU, v. 81, n 48, pg. F230.

Nolan, M., Liston, G., Prokein, P., Brigham-Grette, J., Sharpton, V.L., Huntzinger, R., 2003, Analysis of lake-ice dynamics and morphology on Lake Elgygytgyn, NE Siberia, using synthetic aperture radar (SAR) and Landsat: Journal of Geophysical Research, 108, D2, ALT3.1-ALT3.12.

Nolan, Matt, 2001. SAR Measurement of Ice Dynamics of Lake El'gygytgyn, Siberia. EOS Transactions, AGU, v. 82, n. 47, pg. F458

Nolan, Matt, 2001, Modern Process Studies at Lake El'gygytgyn, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Nolan, Matt, 2001, Monitoring, Hydrology and Remote Sensing, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Peters, Cynthia and V.L. Sharpton, 2001, Remote Sensing in the Vicinity of the El'gygytgyn Impact Crater, Siberia at AGU Fall Meeting 2001 in San Francisco on December 11, 2001.

Peters, Cynthia and V.L. Sharpton, 2003, Using Landsat ETM+ data to discriminate volcanic rocks around El'gygytgyn Crater, Siberia at ASPRS 2003 Annual Meeting in Anchorage, AK on May 7, 2003.

Sharpton, Virgil L., 2001, Drilling into El'gygytgyn Crater: What we can Expect Based on the Terrestrial and Planetary Cratering Records, ICDP Sponsored El'gygytgyn Lake

Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Sharpton, Virgil L., O. Yu. Glushkova, P. Layer, P. S. Minyuk, M. Nolan, D. Stone, and V. N. Smirnov, Initial Results of the Russian-US Partnership to Study the Elgygytgyn Crater, European Science Foundation's IMPACT Programme, 7th Workshop, Submarine. Craters & Ejecta-Crater Correlation, Svalbard, Aug. 29-Sept 3, 2001.

Smirnov, V.N., N.E.Savva, O.Yu.Glushkova, P.S.Minyuk, V.L. Sharpton, Spherules from the El'gygytgyn Meteorite Crater, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Stone, David A., 2001, Modeling the 3.58 Ma El'gygytgyn Impact, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Smirnov, Vladimir, O. Glushkova, P. Minyuk and B. Sharpton, New Data on the Morphology of the Impact Crater of El'gygytgyn Lake, ICDP Sponsored El'gygytgyn Lake Workshop Science Results & Plans for Deep Drilling, Amherst, Massachusetts November 10-12, 2001.

Appendix I: NOLAN ET AL., 2003 ABSTRACT AND ACKNOWLEDGEMENT

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D2, 8162, doi:10.1029/2001JD000934, 2003

Analysis of lake ice dynamics and morphology on Lake El'gygytgyn, NE Siberia, using synthetic aperture radar (SAR) and Landsat

Matt Nolan,[1] Glen Liston,[2] Peter Prokein,[1] Julie Brigham-Grette,[3] Virgil L. Sharpton,[4] and Rachel Huntzinger[1]

Received 7 June 2001; revised 17 January 2002; accepted 17 May 2002; published 27 November 2002.

[1] A time series of more than 450 combined ERS-2, Radarsat-1, and Landsat-7 scenes acquired between 1998 and 2001 was analyzed to develop a fairly complete picture of lake ice dynamics on Lake El'gygytgyn, NE Siberia (67.5°N, 172°E). This 14-km^3 lake partially fills a meteorite impact crater formed 3.6 million years ago and is home to a paleoenvironmental coring project. The duration of lake ice cover and the onset of lake ice breakup are important both to interpretations of the archived sediment core record and to future drilling projects that will use the ice as a stable platform. Ice formation, snowmelt, and ice breakup likely occur in late October, mid-May, and early July, respectively. These data were used to validate a one-dimensional energy-balance lake ice model, which can now be used to hindcast paleoclimate based on core proxy information. Synthetic aperture radar (SAR) backscatter from the lake ice also revealed unusual spatial variations in bubble content, which were found to indicate the level of biological productivity in the sediments directly beneath the ice, with the highest productivity located in the shallowest (0 - 10 m) as well as the deepest (170 - 175 m) regions of the lake. Seismic data indicates that the backscatter anomaly above the deepest water is collocated with the central peak of the impact crater, 500 m below the surface. Several hypotheses are presented to explain this anomaly. Regardless of cause, the fact that large spatial variations in biological productivity exist in the lake has important implications for selecting the locations of future sediment cores. *INDEX TERMS:* 1640 Global Change: Remote sensing; 1845 Hydrology: Limnology; 1630 Global Change: Impact phenomena; 1863 Hydrology: Snow and ice (1827); 1878 Hydrology: Water/energy interactions; 1615 Global Change: Biogeochemical processes (4805); *KEYWORDS:* lake ice, energy balance, lake modeling, Chukotka, Russia, climate

Citation: Nolan, M., G. Liston, P. Prokein, J. Brigham-Grette, V. L. Sharpton, and R. Huntzinger, Analysis of lake ice dynamics and morphology on Lake El'gygytgyn, NE Siberia, using synthetic aperture radar (SAR) and Landsat, *J. Geophys. Res.*, *107*, 8162, doi:10.1029/2001JD000934, 2002. [printed *108*(D2), 2003]

1. Introduction

1.1. Background

[2] El'gygytgyn Crater (pronounced el-je-git'-gin) was formed by a meteorite impact 3.6 million years ago [*Layer*, 2000], at 67.5°N and 172°E (Figure 1), and the lake that formed inside it has since become an excellent paleoenvironmental archive site. At the time of impact, most of the Arctic was forested all the way to the Arctic Ocean, and a million years passed before the first glaciation of the Northern Hemisphere began [*Brigham-Grette and Carter*, 1992]. The lake is currently about 12 km in diameter and sits inside a crater roughly 18 km in diameter. The maximum lake depth is about 175 m, with more than 350 m of sediments deposited since the impact [*Niessen et al.*, 2000]. This large oligotrophic lake has a volume of 14.1 km^3 and a surface area of 117 km^2, with approximately 50 inlet streams draining the 293 km^2 crater area (Nolan, unpublished data). It is located in a remote area of Chukotka that is rarely visited by humans. The crater is the best preserved on Earth for its size [*Dence*, 1972; *Dietz and McHone*, 1976], and the lake is only one of a handful formed inside of craters identified as impact craters [*Lehman et al.*, 1995]. The lake has likely never gone dry since its formation (M. Nolan, unpublished data, 2000) and the area has never been glaciated [*Glushkova*, 1993], indicating that sediments here are continuous and undisturbed. In winter of 1998 we recovered a sediment core containing a 300,000 year climate-record from Lake El'gygytgyn (Lake E); this is the oldest terrestrial sediment core yet recovered from the Arctic. Core interpretations have already yielded important controls on the state of the hydrological cycle, the energy balance, the

[1]Water and Environmental Research Center, Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, Alaska, USA.
[2]Department of Atmospheric Sciences, Colorado State University, Colorado, USA.
[3]Department of Geosciences, University of Massachusetts Amherst, Amherst, Massachusetts, USA.
[4]Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

0148-0227/02/2001JD000934$09.00

tive than the surrounding area for a long time (possibly millions of years), it is conceivable that they may be slightly more consolidated, if for no other reason than upward mass loss through bubble formation. It is also conceivable that gas or water percolating up from below throughout time would further tend to differentially consolidate the sediments in this location. There is some seismic evidence for both this consolidation and for piping structures between the peak and lake bed, though more measurements are required to conclusively verify this. This consolidation and bed-deepening process would then reinforce increased attraction of the warmer shelf-water there, further enhancing the biological production and further consolidating the sediments.

[30] That a region of higher biological production may exist in the region of interest for future sediment cores is significant, because this production can significantly change the nature of the sediments after they are deposited. For instance, the 1998 core shows clear changes between oxic and anoxic conditions. This core location is near the outer boundary of ice region 3 (Figure 3, blue cross), suggesting it is an area of lower productivity than the deepest part of the lake. During glacial summers, it is possible that a moat formed even though the ice did not completely break up, such that oxygen could be replenished here and then carried down to the deepest part of the lake with the density-driven current from the relatively warmer shelves. Thus a core taken in ice region 4 may show a somewhat different oxic/anoxic signature throughout the entire core than the core taken in region 3. This further suggests that cores taken in both locations will help us paint a more complete picture of the paleoenvironment than cores from only a single location, since the productivity of both regions have identical atmospheric drivers.

5. Conclusions

[31] Spaceborne SAR is a powerful tool for understanding the dynamics of lake ice formation, morphology, and melting, and this information has given us many important clues that will aid in the interpretation of our sediment core proxies from Lake El'gygytgyn. We were able to determine dates for lake ice formation, snowmelt, and ice melt to within a few days for each of the past four winters. We were able to model the timing of these events fairly accurately using only air temperature to drive a one-dimensional lake ice model. Bubble content and morphology of the ice were also found to vary spatially and temporally, and this has important implications toward our paleoclimatic interpretations of sediment cores taken from this lake.

[32] **Acknowledgments.** This material is based upon work supported by the National Science Foundation under Grant 0075122 to MAN and Grant 9905813 to JBG. Support was also provided by NASA under Grant NAG5-8722 from the Joint U.S.–Russian Research in Space Sciences Program (JURRISS) to VLS. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation or NASA. Support was also provided by the Alaska SAR Facility. ERS-2 is owned by the European Space Agency and Radarsat-1 is owned by Radarsat International, who hold copyrights on all data acquired.

References

Brigham-Grette, J., and L. D. Carter, Pliocene marine transgressions of northern Alaska: Circumarctic correlations and paleoclimate, *Arctic*, *45*, 74–89, 1992.

Brigham-Grette, J., et al., Preliminary lake coring results from El'gygytgyn Crater, Eastern Siberia, *Eos Trans. AGU*, *79*(45), F477, 1998.

Brigham-Grette, J., et al., Paleoclimate record of El'gygytgyn Crater Lake, NE Siberia: Pilot cores extended to 200 ka, *Paleoclim. Arct. Lakes Estuar. Newsl.*, *7*(Summer), 7, 1999.

Brigham-Grette, J., C. Cosby, M. Apfelbaum, and M. Nolan, The lake El'gygytgyn sediment core: A 300 ka climate record from the terrestrial Arctic, *Eos Trans. AGU*, *82*(48), F752, 2001.

Chapman, W. L., and J. E. Walsh, Recent variations of sea ice and air temperatures in high latitudes, *Bull. Am. Meteorol. Soc.*, *74*(1), 33, 1993.

Cosby, C., J. Brigham-Grette, and P. Francus, The IMPACT Project: Sedimentological studies of the paleoclimate record from El'gygytgyn Crater Lake, *Eos Trans. AGU*, *79*(45), F230, 2000.

Dence, M., The nature and significances of terrestrial impact structures, in *24th International Geological Congress: Proceedings (Planetology)*, pp. 77–89, Montreal, 1972.

Dietz, R., and J. McHone, El'gygytgyn: Probably the world's largest meteorite crater, *Geology*, *4*, 391–392, 1976.

Glushkova, O., Geomorphology and history of relief development of El'gygytgyn Lake Region, in *The Nature of the El'gygytgyn Lake Hollow*, edited by V. F. B. a. I. A. Chereshnev, pp. 26–48, Magadan FEB, Russian Academy of Science, 1993.

Hobbie, J., Polar limnology, in *Lakes and Reservoir*, edited by I. Tarib, pp. 63–105, Elsevier Sci., Amsterdam, 1984.

Jeffries, M., K. Morris, and W. F. Weeks, Structural and stratigraphic features and ERS-1 Synthetic Aperture Radar backscatter characteristics of ice growing on shallow lakes in NW Alaska, winter 1991–1992, *J. Geophys. Res.*, *99*(C11), 22,459–22,471, 1994.

Jeffries, M., K. Morris, and G. Liston, A method to determine lake depth and water availability on the North Slope of Alaska with spaceborne imaging radar and numerical ice growth modelling, *Arctic*, *49*, 367–374, 1996.

Kalnay, E., et al., The NCEP/NCAR 40 year re-analysis project, *Bull. Am. Meteorol. Soc.*, *77*, 437–471, 1996.

Kong, M., W. Jan Gunnar, and E. Isaksson, Measuring snow and glacier ice properties from satellite, *Rev. Geophys.*, *39*(1), 1–27, 2001.

Kozlenko, N., and M. Jeffries, Bathymetric mapping of shallow water in thaw lakes on the North Slope of Alaska with spaceborne imaging radar, *Arctic*, *53*, 306–316, 1999.

Layer, P., Argon-40/Argon-39 age of the El'gygytgyn impact event, Chukotka, Russia, *Meteorit. Planet. Sci.*, *35*, 591–599, 2000.

Lehman, A., D. Imboden, and J. Gat, *Physics and Chemistry of Lakes*, Springer-Verlag, New York, 1995.

Liston, G., and D. Hall, An energy balance model of lake-ice evolution, *J. Glaciol.*, *41*, 373–382, 1995a.

Liston, G., and D. Hall, Sensitivity of lake freeze-up and break-up to climate change: A physically based modelling study, *Ann. Glaciol.*, *21*, 387–393, 1995b.

Magnusson, J., et al., Historical trends in lake and river ice cover in the Northern Hemisphere, *Science*, *289*, 1743–1748, 2000.

Niessen, F., C. Kopsch, B. Wagner, M. Nolan, and J. Brigham-Grette, The IMPACT Project: Seismic investigations of Lake El'gygytgyn, NE Russia—Implications for sediment thickness and depositional environment, *Eos Trans. AGU*, *81*(48), F320, 2000.

Nowaczyk, N., et al., Magnetostratigraphic results from impact crater lake El'gygytgyn, north-eastern Siberia: A possibly 300 kyr long terrestrial paleoclimate record from the Arctic, *Geophys. J. Int.*, in press, 2002.

Rott, H., and T. Nagler, Capabilities of ERS-1 SAR for snow and glacier monitoring in alpine areas, in *Proceedings of the 2nd ERS1 Symposium: Space at the Service of Our Environment, Hamburg, Germany, 11–14 October 1993*, SP-361, pp. 965–970, European Space Agency, Paris, 1994.

Weeks, W. F., P. Seilmann, and W. Campbell, Interesting features of radar imagery of ice-covered North Slope lakes, *J. Glaciol.*, *18*, 18–27, 1977.

Walter, G., F. C. Chapin, K. R. Everett, J. E. Hobbie, D. Kane, W. Oechel, C. L. Ping, W. S. Reeburgh, D. Walker, and J. Walsh, The Arctic Flux Study: A regional view of trace gas release, *J. Biogeogr.*, *22*, 365–374, 1995.

Wetzel, R., *Limnology: Lake and River Ecosystems*, 3rd ed., Academic, San Diego, Calif., 2001.

J. Brigham-Grette, University of Massachusetts Amherst, Amherst, MA, USA.

R. Hunzinger, M. Nolan, and P. Prokein, Water Research Center, Institute of Northern Engineering, University of Alaska Fairbanks, 441 Duckering Building, P.O. Box 755860, Fairbanks, AK 99775-5860, USA (matt.nolan@uaf.edu)

G. Liston, Colorado State University, CO, USA.

V. L. Sharpton, Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775-5860, USA.

Appendix II: BIBLIOGRAPHY OF TRANSLATED WORKS ON ELGYGYTGYN CRATER

* indicates abstract only has been translated

Belyi, V.F. 1982. Elgygytgyn lake depression--meteorite crater or geologic structure of new epoch of development of central Chukotka? *Tikhooceanskaya Geologiya*, p. 85-91.

Belyi, V.F. (ed). *The nature of the Elgygytgyn Lake Hollow (the problems of study and preservation)*. Russian Academy of Sciences, Far East Branch, Northeast Interdisciplinary Research Institute. Magadan: 1993. The following excerpt has been translated: "Geomorphology and History of Relief Development of Elgygytgyn Lake Region" By O.Yu. Glushkova, p. 26-48.

Belyi, V.F.; Raikevich, M.I. *The Elgygytgyn Lake Hollow*. Russian Academy of Sciences, Russian Academy of Sciences, Far East Branch, Northeast Interdisciplinary Research Institute. Magadan: 1994. The following excerpts have been translated: "Geologic structure of environment of Lake Elgygytgyn Hollow" and "Morphostructure" p. 5-14.

Belyi, V.F., Raikevich, M.I. 1996. Geology of Elgygytgyn Lake Depression Impactites. *Moscow Bulletin About Tests of Nature, Geologic Division*, v. 71, n.1, p. 56-72.

Excerpts from "Andesitic formation," from *The Formation and Tectonics of the Okhotsk-Chukotka Volcanogenic Field* by V.F. Belyi

Excerpts from "Ignimbritic formation," from *The Formation and Tectonics of the Okhotsk-Chukotka Volcanogenic Field* by V.F. Belyi

Feldman, V.I.; Granovski, L.B.; Naumova, I.G.; Nikishina, N.N. 1979. Some samples of the chemical composition of impactites from Elgygytgyn crater, Chukotka. *Meteoritics, USSR Academy of Sciences*, p. 382-385.

Feldman, V.I.; et al. 1981 "Elgygytgyn Meteorite Crater." *Impactites*, p. 70-92.

*Gurov, E.P.; Valter, A.A.; Gurova, E.P.; Serebrennikov, A.I. 1978. Explosive meteorite crater Elgygytgyn in Chukotka. *USSR Academy of Sciences Bulletin*, v.240 n.6, p. 1407-1410.

*Gurov, E.P.; Gurova, E.P.; Rakitskaya, R.B. 1979. Stishovite and coesite in shock-metamorphosed rocks from Elgygytgyn crater in Chukotka. *USSR Academy of Sciences Bulletin*, v.248 n.1, p. 213-216.

*Gurov, E.P.; Gurova, E.P. 1979. Stages of shock metamorphism in volcanogenic rocks of acidic composition (for example Elgygytgyn meteorite crater, Chukotka). *USSR Academy of Sciences Bulletin*, v. 249 n.5, p. 1197-1202.

*Gurov, E.P.; Gurova, E.P.; Gorodinsky, M.E. 1980. Shock-metamorphosed rocks and impactites from Elgygytgyn crater in Chukotka. *Cosmochemistry of Meteorites, Lunar and Planetary Science*, p. 144-149.

Appendix II: BIBLIOGRAPHY OF TRANSLATED WORKS ON ELGYGYTGYN CRATER

Gurov, E.P.; Ryabenko, V.A.; Gurova, E.P. Structure of young meteorite craters (for example Elgygytgyn crater in Chukotka). *Geologic Journal*, n.1, p. 130-134.

*Gurov, E.P.; Gurova, E.P. 1980. Shock-metamorphosed rocks from Elgygytgyn meteorite crater in Chukotka. *USSR Academy of Sciences: Meteoritics*, v.39, p. 102-109.

*Gurov, E.P.; Gurova, E.P. 1980. Impactites and glass bombs from Elgygytgyn meteorite crater in Chukotka. *Geologic Series, USSR Academy of Sciences*, n.1, p. 54-61.

Gurov, E.P.; Gurova, E.P. 1981. *Geologic structure and shock metamorphism of volcanogenic rocks of Elgygytgyn meteorite crater.* Ukrainian SSR Academy of Sciences, Preprint 81-4. The following excerpt from this volume was translated: "Geologic structure of Elgygytgyn meteorite crater," p. 6-22.

*Gurov, E.P.; Gurova, E.P. 1982. Composition of impactites from Elgygytgyn crater and their content of nickel and chromium. *Cosmogenic Particles on Earth*, p. 120-121.

Gurov, E.P.; Gurova, E.P. 1983. Regularity in expansion of break-up around meteorite craters (for example Elgygytgyn crater). *USSR Academy of Sciences Bulletin*, v. 269 n.5, p. 1150-1153.

*Gurov, E.P.; Komarov, A.M.; Koltsova, T.V.; Gurova, E.P. Fission track dating of glass impactites in Elgygytgyn crater. *Ukrainian Academy of Sciences*, n.10, p. 11-13.

*Gurov, E.P.; Gurova, E.P. 1984. Alkaline elements in impactites of meteorite craters Elgygytgyn and Boltysh. *Cosmochemics and Meteoritics*, p. 205-209.

*Gurov, E.P.; Gurova, E.P.; Rakitskaya, R.B. 1985. Electron microscope study of shock metamorphism in some rock-forming minerals (for example Elgygytgyn crater). *USSR Academy of Sciences: Meteoritics*, v.44, p. 168-172.

Appendix II: EL'GYGYTGYN DRILLING WORKSHOP ANNONCEMENT

It is with pleasure that I announce the dates for our upcoming

El'gygytgyn Crater Lake Workshop - Science Results and Plans for Deep Drilling.

This meeting will be held here in Amherst on November 10-11-12, 2001 directly after the National Geological Society of America meetings in Boston. The meeting will be held at the Lord Jeffery Inn (http://www.pinnacle-inns.com/lordjefferyinn/) near the heart of town and within walking distance of the University of Massachusetts. Logistics for the meeting will be available on a web page in the fall.

The purpose of the meeting is to:

Further synthesize the data obtained from the two earlier expeditions to the lake;

Develop a strategy and schedule for future field and subsequent laboratory work;

Discuss the permitting for future field work and determine responsibilities;

Plan the logistics and calculate costs for future field and laboratory work;

Reconcile and plan for grant applications to national and international funding agencies;

Develop goal-oriented partnerships between our paleoclimatic interests and the interests of planetary scientists curious in crater origins, structure, and life in extreme environments (e.g., Mars analogs).

According to ICDP rules, this workshop should be open to scientists from all member countries that have both an interest in the project and new scientific expertise to contribute.

Applications by letter via email to attend the meeting should be sent to me (juliebg@geo.umass.edu) with the subject line (Lake E application). The steering committee composed of colleagues Martin Melles (Germany) and Pavel Minyuk (Russia) and myself (USA) will evaluate the applications for scientific scope. Applications will be consider until October 10th, a month before the meeting. Please feel free to distribute this message to individuals within your country who might have an interest in this workshop. Images of the crater can be viewed at http://www.uaf.edu/water/faculty/nolan/lakee.html or at http://eclogite.geo.umass.edu/projects/chukotka/elg.html

Should you have any questions, please feel free to contact us. I will be away doing fieldwork in NE Russia from July 6 to September 1, however Martin Melles (melles@rz.uni-leipzig.de) will likely be available by email until I return. Thank you for supporting this exciting next step in our planning.

Sincerely,

Julie Brigham-Grette
Professor and Associate Department Head
Geosciences